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From room temperature cyclotron to superconducting cyclotron, the contemporary Indian scenario

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Abstract : The Changing scenario of the cyclic accelerator development, from room temperature to superconducting is discussed ; the technology and scientific motivations are overviewed.

Keywords : Cyclic accelerator, room temperature to superconducting cyclotron, technical and scientific development.

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1. Introduction

Like the proverbial beauty is what the beholder sees, the looking glasses of the twentieth century see what the nature reveals, the energy of the accelerators decides the resolution of the constituents of nature's building blocks.

If the projectile's energy is of the order of a hundred MeV or so, the nucleus looks to be constituted of baryons, the neutrons and the protons, with the mesonic degrees of freedom still suppressed. The nucleus in this energy regime only reveals its so called macroscopic properties, its single particle nature contradistinctive to its collective nature, its shell model characteristics to its dizziness with high spin-with the advent of heavy ions as projectiles, all these characteristics get somewhat exaggerated in much splendour. With further increase in the energy some exciting, possibilities open up, like an impending tide, the nucleus is sweapt away beyond the threshold of the velocity of sound, piling up nuclear matter, creating head shocks and slide splash, crawling up the density ladder picking up points in the virginal teritory of the nuclear equation of state. Beyond the pionic threshold the excited baryons show up with the sudden emergence and eventual assertion of non nucleonic degress of freedom.

As the energy reaches the threshold of a billion electron volts, of the order of the baryonic mass, the internal structure of the baryons begin to be important. The quark and gluonic degrees of freedom turn important.

In this panaroma, India's contemporary accelerator programme is still at the first stage, with the eighth five-year plan coming up the threshold of energy will take us to the second stage. The talk is essentially centered around this

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theme. It should be added that the CERN collaboration will probably usher in the quark degrees of freedom from an international rather than national arena, a point briefly discussed in this talk.

Table I. List of the users group.

1. Saha Institute of Nuclear Physics, Calcutta
2. Calcutta University, Calcutta
3. Jadavpur University, Calcutta
4. Indian Association for the Cultivation of Science, Calcutta
5. Variable Energy Cyclotron Centre, Calcutta
6. Bose Institute, Calcutta
7. Kalyani University, Nadia
8. Burdwan University, Burdwan
9. Divisions of BARC, Bombay
   (a) Nuclear Physics
   (b) Radiochemistry
   (c) Radiopharmaceuticals
   (d) Analytical Chemistry and Chemistry
   (e) Metallurgy
   (f) Health Physics
10. Tata Institute of Fundamental Research, Bombay
11. Banaras Hindu University, Varanasi
12. Udaipur University, Rajasthan
13. Mysore University, Mysore
14. Bangalore University, Bangalore
15. Panjab University, Chandigarh
16. Aligarh Muslim University, Aligarh
17. I. G. C. A. R., Kalpakkam
18. Calicut University, Kerala
19. I. I. T., Kanpur
20. Andhra University, Waltair
21. N. E. H. U., Shillong
22. Nuclear Science Centre, New Delhi
23. Mangalore University, Manasagangothri
24. Institute of Physics, Bhubaneswar
25. Nagpur University, Nagpur
26. South Gujarat University, Surat
27. Osmania University, Hyderabad
28. I. I. T., Kharagpur
29. M. D. University, Rohtak
30. Saurashtra University, Rajkot
31. Kurukshetra University, Kurukshetra
32. Gulbarga University, Gulbarga
33. Poona University, Pune

It is my belief that PATPPA in future will do well to give us the flavour of such areas-this will excite and stimulate the young and the initiated.

2. The Cyclotron Centre

The Cyclotron at Calcutta has been running fairly smoothly round the clock for quite some time. The experimental studies carried out can be divided in three broad categories – Nuclear Physics taking up about 70% of its running time, the rest of the time taken up by a whole host of applied and semi applied studies and of course, a certain small portion of time is usually utilised for beam development and related activities. A total of thirty three institutions from all over the country use the cyclotron.

A brief outline of the nuclear physics studies is given in the following :

(i) Nuclear Reaction studies, elastic, inelastic transfer and knockout reactions.

(ii) Charged particle spectroscopy.

(iii) High spin states-γ-ray detection with NaI detectors and/or multiplicity filter compton suppression systems.

(iv) Nuclear molecules.

(v) Heavy ion fragmentation studies using gas detectors.

(vi) Fusion studies and Limiting Momentum Transfer.

(vii) Alpha induced fission studies.

More than seventy papers in reputed journals have already been published, a list of the users group is given in Table 1.

Some of the multiparameter experiments have been possible essentially because of the pioneering work carried out by VEC Centre's computer group in developing the CAMAC based on line data acquisition system. The ND 560/100 based data acquisition system has been working rather satisfactorily for quite some time.

Considerable amount of theoretical physics activities are carried out at the cyclotron centre, broadly classified as follows :

(a) Nuclear Reactions : Optical potentials, Heavy ion induced reactions, Dispersion relations and their applications.

(b) Deep inelastic collisions : Studies related to the Marcovian process and the role of collective degrees of freedom.

(c) Intermediate energy heavy ion collisions : Limiting temperature, Hot spots, shock waves, eq. of state.

(d) Elastic and inelastic break up of light ions with special emphasis on the astrophysical aspects.

(e) Studies related to Quark-Gluon Plasma : Signals such as dileptons, inclusive photons and diphotons, Early Universe Cosmology and the inhomogenity of the microsecond universe and finally Neutron Stars and SN 1987A.

Immediate new activities :

(a) The Electron Cyclotron Resonance source (ECR), shown in Figure 1 is almost ready for the test bench – this will bring in an entirely new era of heavy ion studies ; a global comparative scenario is in Figure 2. The design of the ECR source is developed by our collegues at the Cyclotron

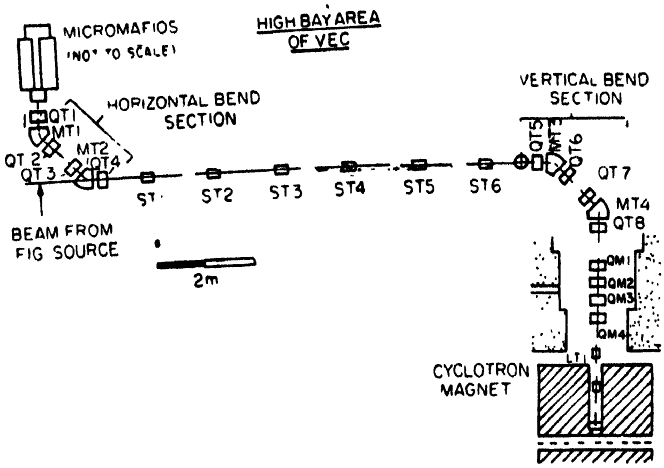

Figure 1. ECR lay out at VECC.

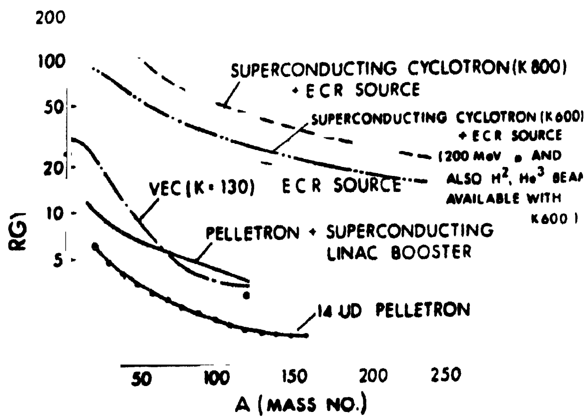

Figure 2. Energy vs mass no. plots for the proposed superconducting cyclotron and the other facilities currently under development.

with one microwave generator typically about $\sim$ 9.0 GHz. We hope to install the ECR source early next year when the machine will be taken away from the users for a while.

(b) Studies related to short-lived isotopes far from the stability line is yet another new vital area of activity. The on line isotope seperator ISOL with the associated helium jet facility is going to be complete in the next few months for operation, Figure 3.

This kind of activity has also brought us to a very fruitful collaborative work with our colleagues at RIKEN, Japan. Two of our colleagues recently undertook an experimental programme at RIKEN, with them as spokespersons, rather successfully. This possibility has opened up an

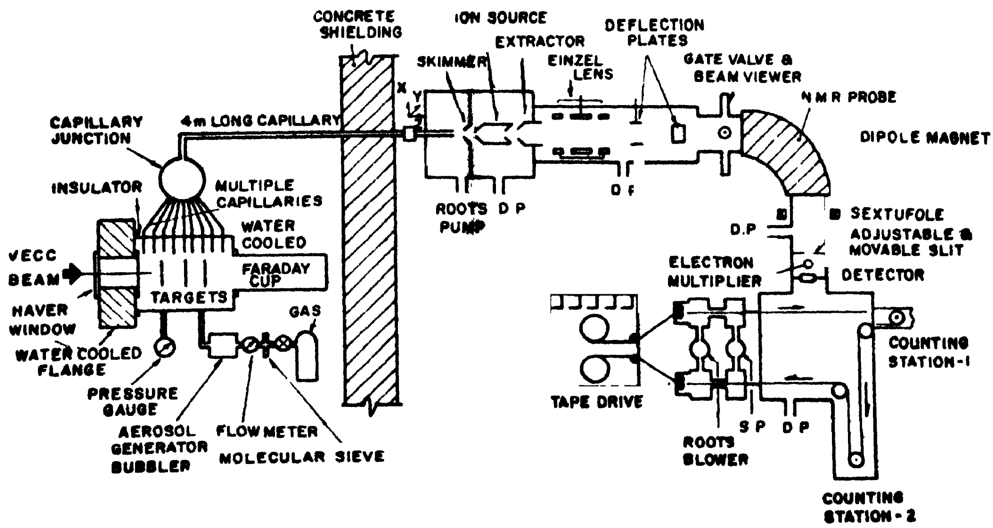

Figure 3. The ISOL on line isotope seperator facility at VECC.

entirely new area of research and that is to use radioactive beams for studies of exotic properties of nuclei far from the stability line.

(c) WA80 Collaboration with CERN : The theoretical activities related to direct photons as possible signals of quark gluon plasma led us to collaborate with WA80 experiments at CERN. At present our group is excitedely persuing development of a photon counter for measuring the total number of photons. Consisting of about 15000 pads of detectors, this detector is going to be used in the coming Sulphur run in the summer of 1991. Considered as one of the most challenging experimental programme, it is felt that such a collaboration will bring our activities in the forefront of experimental research of India.

(d) Helium Extraction Project at Bakreswar, near Calcutta : It was long envisaged by Professor S N Bose and his young research colleage, Professor Shyamadas Chatterjee that the gas emanating from the Bakreswar and Tantloi hot springs contain comparitively large percentage of noble gas the helium content being about 2% of the total output. Excavation work is already in progress with the ultimate goal of accumulating enough helium gas to run the superconducting cyclotron (see later) to be built during the VIII-th Five Year Plan period.

The project has yet another intriguing aspect, there is already some evidence to suggest that the tritium level of the water at Bakreswar is at least sixty times more than ordinary water. The question therefore comes as to what can be the source of this helium ? It is well known that the ratio $^3He/^4He$ will decide a number of burning possibilities. Experimental programmes are already in the agenda to determine this ratio.

(e) Regional Radiation Medicine Centre at Thakurpukur at the outskirts of Calcutta : A consistent effort is being made to develop a diagnostic centre at RRMC with a Radio Immuno Assay kit and a gamma camera already being installed. There is a great promise in this campaign to provide the all important diagnostics for poor patients in the eastern sector, It is hoped that it is not long before a captive medical cyclotron will be installed at this centre.

3. Super Conducting Cyclotron (SC)

With the backdrop just discussed, clearly time has come to plan ahead as the century draws to its close. It is also quite evident that if we were to build a cyclic accelerator, which happens to be our niche, it should be, first, of a higher energy regime, and second almost certainly superconducting. It should also be of variable energy to meet India's hetrogenous demands of users and finally it should bring in a new technology for our country. Considering all these aspects, it has now been decided to build a superconducting cyclotron of typical energy of 200 MeV/nucleon, (K$\sim$800) beyond the threshold of nuclear sound and pionic mass.

First of all what are the central physics motivations ? Apart from the areas of research already mentioned in comparatively low energy physics such as high

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Table 2. Superconducting cyclotrons.

Lab	K_{bend}	K_{foc}	Status
Chalk River	520	100	Internal beam Aug. 1985, External beam Nov. 1985
NSCL (MSU)	500	160	Physics program since Nov. 1982
Milan/Catania	800	200	RF resonator operating fall 1984, Magnet testing fall 1986
Msu	1200	400	Magnet full field may 1984, First beam spring 1987*
Texas A and M	500	160	Magnet full field July 1985, First beam summer 1987*
Msu/Harper Hosp.	100	100	Magnet tests Nov. 1986, First beam February 1987
Munich	85	43	Separated orbit cyclotron prototype for K=2400
Orsay/Groningen	600	200	Project starts late 1985 Heavy ions and *Protons*

*Operating

Table 3. Parameters of the K800 cyclotron.

K_{bend} at 50 Tesla	1200
$K_{focussing}$	400
Magnet	
Pole radius	104.14 cm
No. of sectors	3 (46° wide flaring to 51° wide)
Average operating field	3.0-5.0 Tesla
Yoke height	297.18 cm
Yoke diameter	299.72 cm (inner), 441.96 cm (outer)
No. of trim coils	22
Maximum current in any trim coil	400 A
Maximum total trim coil power	60 kW
Valley gap	91.4 cm
Hill gap	7.6 cm
Hill to valley field difference	1.5 Tesla
Total hill field	6.2 Tesla
Superconducting coil material	NbTi embeded in thick copper matrix
Current density	35 to 40 amps/mm^2
R. F. System	
Operating range	9.0 to 27.5 MHz
No. of Dees	Three
Max. dee voltage	200 kV
Dee gap	2 cm
Phase stability	0.1°
Amplitude stability	1 in 10^4
Total DC power	1.2 MW
Injection	
Ion source	ECR
Inflector	Spiral
Maximum injection voltage	20 kV
Extraction	
Deflector	2 nos. electrostatic
Deflector voltage	125 kV/cm
Vacuum System	
Operating pressure	10^{-7} torr
Volume	1 m^3
Surface area	50 m^2
Pumping system	Cryo-Turbo-Rotary

Table 3. (Contd.)

Cryogenic system	
Heat load	500 W at 80 K 40 W at 20 K 20 W at 4.2 K
Colling power	15 lit/hr of liquid helium in refrigerator mode 50 lit/hr of liquid helium in liquifaction mode

spin states, dizzing nucleus – fusion fission or incomplete fusion, one very important feature is pion production and the other is production of shock waves, leading to slide splash of nuclear matter. Evidently, the nuclear density in these circumstances will go beyond the normal density so that certain yet unknown features of nuclear equation of state will be probed.

Technologically superconducting cyclotron can be considered at the forefront of technology – 42 kms of superconducting wire, Niobium Titanium, is to be wounded to produce the high rigidity magnetic field – the spin off in technology is thus considerable.

The great advantage of the superconducting cyclotrons is its compactness and thus achieving a large scale magnetic field of 6.2 Tesla with a magnet weighing only 250 tons, just about the same weight as of our room temperature cyclotron.

A list of the centres in the world, operating or about to operate the superconducting cyclotron is given in Table 2. We hope to follow the technology rather closely of the MSU, K = 500 cyclotron. The details of our understandings with our American colleagues are yet to be worked out.

The cryogenics, RF system and the winding of the superconducting coils are the three main features of the cyclotron. The computer control system for diagnos-

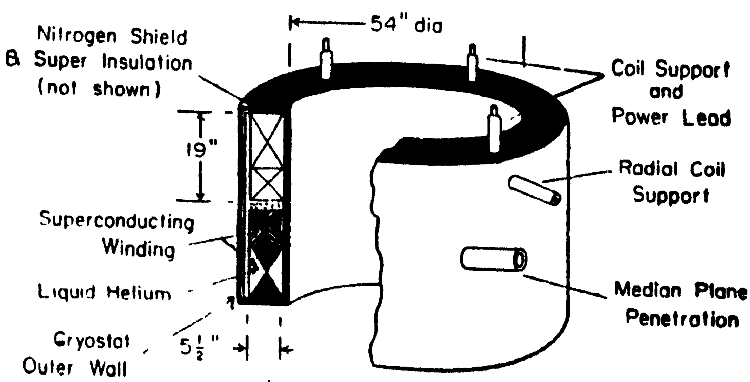

Figure 4. The superconducting coil and the magnet assembly.

tics and running of the cyclotron is yet another important area. Some of the main features of SC are shown in Figures 4, 5 and Table 3.

Once the temperature goes beyond 7°K approximately, the coils cease to be superconducting and thus allow the resistance to go up rather rapidly inducing tremendous electromagnetic pressure, a phenomena known as quenching. At present we are studying the various modalities already developed to sustain

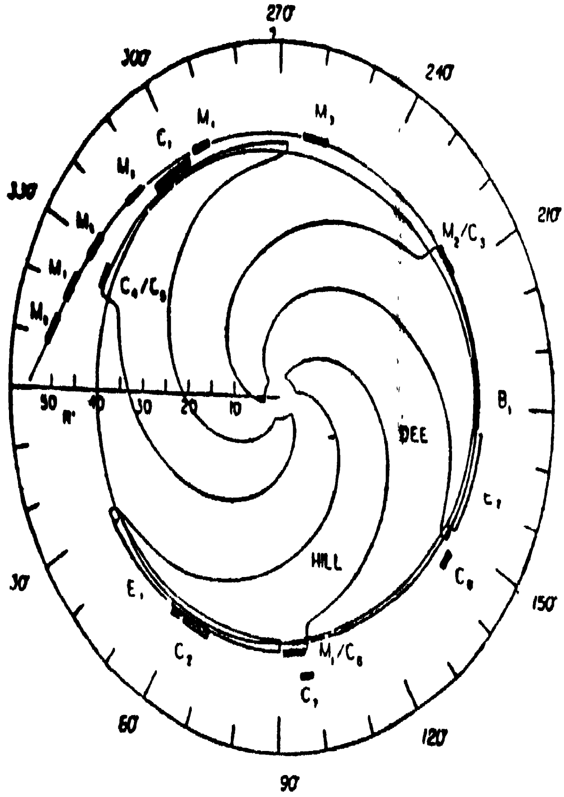

Figure 5. Extraction system layout.

quenching. AGOR in France has decided to put the superconducting coils in epoxy potting wheres the Americans keep it floating in liquid helium, the former apt to quench more often, the latter is supposed to be cryostatically more stable. After much discussions, we are slowly coming round to believe that we shall probably adopt the American design.

I have said all there is to say about future programmes. At the end, I will like to only conclude by saying that we are going through interesting times.